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THE NEW PRECIPITATION SECTION OF THE ATLAS OF AMERICAN AGRICULTURE.

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[Harvard University, March 17, 1922.]

Introduction.—The preparation of a section on Climate for the new *Atlas of American Agriculture* marks a very important advance in the accurate charting and discussion of many of the essential features of the climates of the United States. As yet, but one part of this section has been issued in its final form, viz, that on Frost.[1] The *Precipitation* section has been printed but not yet bound or distributed. Sets of the loose sheets have, however, been sent to a limited number of teachers and others to whom the material is of immediate practical use. The *Humidity* folio is still to be lithographed and printed. The complete *Precipitation* and *Humidity* section will therefore probably not be ready for distribution in its final form, for several months. The *Temperature* section is, unfortunately, still further from completion.[2] Advance publication has been made of the new mean annual, monthly, and seasonal rainfall maps,[3] all of which have previously been reviewed by the present writer.[4]

General description of the precipitation section.—The precipitation section comprises 85 figures, of which 16 are diagrams and 69 are maps. Of the maps, 16 show the monthly and seasonal, and one shows the mean annual precipitation. With these, the present discussion does not deal. The text covers 5½ pages. Taken altogether, this new series of charts and diagrams constitutes one of the most notable contributions to climatology of recent years. Not only is the series remarkably complete, more so than any previous set of similar charts, but, what is even more essential, records for a uniform basic period of 20 years (1895–1914) were employed in the construction of all the principal maps and graphs. About 1,600 stations have records for the full 20-year period. Additional shorter records from about 2,000 other stations were also used. These all come within the 1895–1914 period—vary in length from 10 to 19 years, and were reduced to the basic 20-year period by well-known methods. The result is not only a more complete but a far more accurate compilation of precipitation data for the United States than has hitherto been possible. Especially is this true of the more recently settled portions of the country and of the higher altitudes of the West. In the case of these last-named districts the mountain snowfall records were found very useful as a guide in drawing the isohyetal lines. In addition, the amounts of precipitation at the higher elevations (where there is a great lack of actual rainfall records) were inferred from the known increase of precipitation with elevation; from the character of the vegetation, and from the stream flow, wherever reliable data on these conditions were available.

Departures from the average rainfall.—The principal and most immediate object in view in the preparation of this new precipitation folio was to benefit agriculture. From the agricultural standpoint, the mean annual and mean monthly rainfalls are by no means altogether satisfactory. In the case of the former, the period is so long that deficiencies in certain parts of the year which are of critical importance to crops may be wholly concealed by excess precipitation at other times of the year. Further, the annual amounts are often of secondary importance to the seasonal distribution. Nor are the monthly charts always of great value, for they show only the average conditions during the arbitrary unit of a calendar month, which unit often has but little importance in the growth of crops. For these and other reasons, increasing emphasis has lately been laid upon seasonal precipitation charts, which, combining as they do the conditions of three months, give better information regarding the amounts of rainfall available for crops during their critical periods of growth. This new monograph very rightly emphasizes the importance of seasonal precipitation by including five full double-page charts, one each for the four seasons and one for the warm season, April–September, inclusive. An especially noteworthy feature of the new folio is the marked emphasis which it lays upon the departures which may be expected from the average rainfall. More and more, as climatological investigation progresses, is it realized that far too much attention has in the past been paid to *means*. It matters little to the farmer to know that the *mean* or *average* rainfall over his section is sufficient for the growth of a large crop if in some seasons his fields are parched during an "unusually" dry time and in others his crops suffer from "excessive" rains. He needs to know what departures from the average he may expect in the run of the years. He is then in a position to decide for himself what crops he may plant with the greatest probability of success. It is good, therefore, to see at the bottom of each seasonal and monthly chart a graph which shows, for a group of selected stations, the seasonal or monthly precipitation for each of the 20

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[1] See review by R. De C. Ward: "Frost in the United States," *Geogr. Rev.*, vol 7, May, 1919, pp. 339–344.

[2] R. De C. Ward: "Some Characteristics of United States Temperatures," Mo. Weather Rev., November 2, 1921, 49: 595–606; Charts XX.

[3] R. De C. Ward: "Mean Annual Rainfall of the United States, with Notes on the New Chart of Average Annual Precipitation from the 'Atlas of American Agriculture' (Advance Sheet)," *ibid*, July, 1917, pp. 45: 338–345; chart.

J. B. Kincer: "The Seasonal Distribution of Precipitation and its Frequency and Intensity in the United States," *ibid*, September, 1919, 47: 624–631; Charts XVI.

[4] R. De C. Ward: "New Monthly and Seasonal Rainfall Maps of the United States," *Geogr. Rev.*, vol. 9, September, 1920, pp. 173–181, with the four seasonal charts redrawn and somewhat simplified.

years of the basis period on which the chart is based. These diagrams show the variations which are likely to occur from year to year. They indicate the "relative dependability" of the means. Similarly, a full-page set of diagrams (fig. 5) shows the annual precipitation at 56 selected stations, arranged by geographic districts, for each of the years 1895 to 1914, inclusive. The facts here presented show the variations which may be expected from year to year in different sections and the general geographic distribution of these variations. It is seen that the larger variations occur on the Pacific slope, over the Great Plains, and in the Gulf States.

Many other new and economically important details regarding the variability of rainfall are also shown. From a chart of the relative frequency during the period 1895–1914 of an annual precipitation less than 85 per cent of the average (fig. 7), it appears that in the vicinity of Yuma, Ariz., less than 85 per cent of the annual precipitation fell in half the years, while more than 85 per cent of the annual mean fell in over 90 per cent of the years in parts of the Lake region, of the Atlantic Coast States, and of Tennessee. Another chart, of the relative frequency of warm-season precipitation (April–September) less than 75 per cent of the average, brings out facts of great agricultural importance (fig. 11). The warm-season rainfall was less than three-fourths of the average in 8–11 years (of the 20-year period) in southern California and parts of the adjoining States, but, fortunately for the great agricultural interests of the region east of the Rocky Mountains, a warm-season precipitation of less than 75 per cent of the average occurred in only two to four seasons during the 20 years. For each of the eight months July to October the relative frequency of monthly precipitation less than half the average is charted (figs. 58–65). The practical value of these charts may be realized by an examination of the facts which appear on any one of them. Take, e. g., that for July, a critical month for many of our great staple crops. It appears that in the central and eastern portions of the Cotton Belt there are a number of localities where only one July with a deficiency of more than one-half of the average rainfall occurred in 20 years. At some points in no year was the July rainfall less than half the average The districts east of the Mississippi River, as a rule had few deficiencies of 50 per cent. On the other hand, the percentages of frequency of a July precipitation less than half the average are large on the Pacific slope, espcially in California. As a whole, the variations above and below the normal are more frequent west of the Rocky Mountains, especially in summer.

Rainfall types.—The question "*When* does the rain fall?" being, for the agriculturist, often of more importance than the question "How much rain falls?" it is natural and logical that considerable attention should be paid to rainfall types and to illustrations of rainfall distribution through the year. The discussion of this matter occupies somewhat over a page of the text (pp. 16 and 37). In place of the 11 types of seasonal distribution recognized by Prof. A. J. Henry, 6 types are here adopted as sufficient "with respect to their agricultural significance and areas covered."[5] These are named Pacific, Sub-Pacific, Arizona, Plains, Eastern, and Florida and are illustrated by a series of percentage graphs for selected stations, the separate graphs being placed, in their proper locations on a general map of the United States (fig. 13). The question whether these types are permanent or might in some respects be altered if a different series of years were adopted was investigated.

It appeared that the Pacific type is less constant in relative monthly distribution than are the Eastern and the Plains types, but the distinguishing characteristics are maintained, even if different periods of years are used. Caution may, however, well be used in emphasizing the characteristics of the less distinctive types as indicated by the relatively short period of 20 years. The Eastern type (including the originally forested eastern United States except the Florida peninsula) has comparatively uniform precipitation through the year. In general, autumn has the least seasonal rainfall. This is particularly true of the Cotton Belt, and it there constitutes a very favorable condition for cotton picking. The Plains type (including the prairie and Plains regions and extending westward to the crest of the Rocky Mountains) has a marked late spring and summer maximum, with a dry winter. In the Arizona type (western Texas, New Mexico, and Arizona) July and August bring the heaviest rainfall. The Sub-Pacific type (covering most of the country between the Rocky Mountains and the Sierra Nevada and Cascade Ranges, and north of the Arizona type) has most of its precipitation during the winter and spring months. The Pacific type (between the Sierra Nevada-Cascades and the Pacific) has wet winters and dry summers. A heavy late summer or early autumn rainfall characterizes the Florida peninsula.

Four small charts (figs. 21, 31, 41, 51) show the percentages of the annual precipitation which come in each season. In winter the area having the highest percentages of the annual is on the Pacific coast (40–60 per cent); in spring the northern Rocky Mountain and Eastern Foothill regions have the highest percentages (30–35 per cent), but high percentages (over 30 per cent) are found westward into Idaho and Nevada and eastward well onto the Plains. In summer the area of highest percentages is still farther east over the Plains proper (40–50 per cent). There is thus seen to be a seasonal migration of the area of (relatively) heavy precipitation from the Pacific coast eastward to the Great Plains between winter and summer corresponding to the seasons of maximum and of minimum marine and continental controls. The Plains have roughly the following seasonal distribution: Winter, less than 10 per cent; spring, 25–30 per cent; summer, 40–50 per cent; autumn, 15–20 per cent. The percentage of the annual precipitation occurring between April 1 and September 30 is highest (over 70 per cent) over most of the great agricultural region of the eastern United States, embracing the eastern Plains and the Prairie States, a fact which brings out in startling prominence the agricultural importance of the "Plains" type of rainfall, with its late spring and early summer maximum (fig. 3). A small diagram (fig. 4) shows the period of the year within which 50 per cent of the annual precipitation occurs. A double-page chart (fig. 15) gives graphs showing for selected stations the precipitation for each of the 12 months for each of the 20 years (1895–1914). The amount of precipitation is shown by a dot and the average monthly amounts by heavy lines. The graphs show the seasonal variation of precipitation, and also the variations from the monthly precipitation, which may be expected in different sections. The frequency of subnormal monthly rainfalls can be easily determined. On the Pacific coast the variations are large. East of the Rocky Mountains the variations are, as a rule, largest where the average amounts of precipitation are greatest. East from the Great Lakes the variations are comparatively small.

[5] In connection with this, reference may be made to R. De C. Ward: "Rainfall Types of the United States," Geogr. Rev., vol. 4, August, 1917, pp. 131-144.

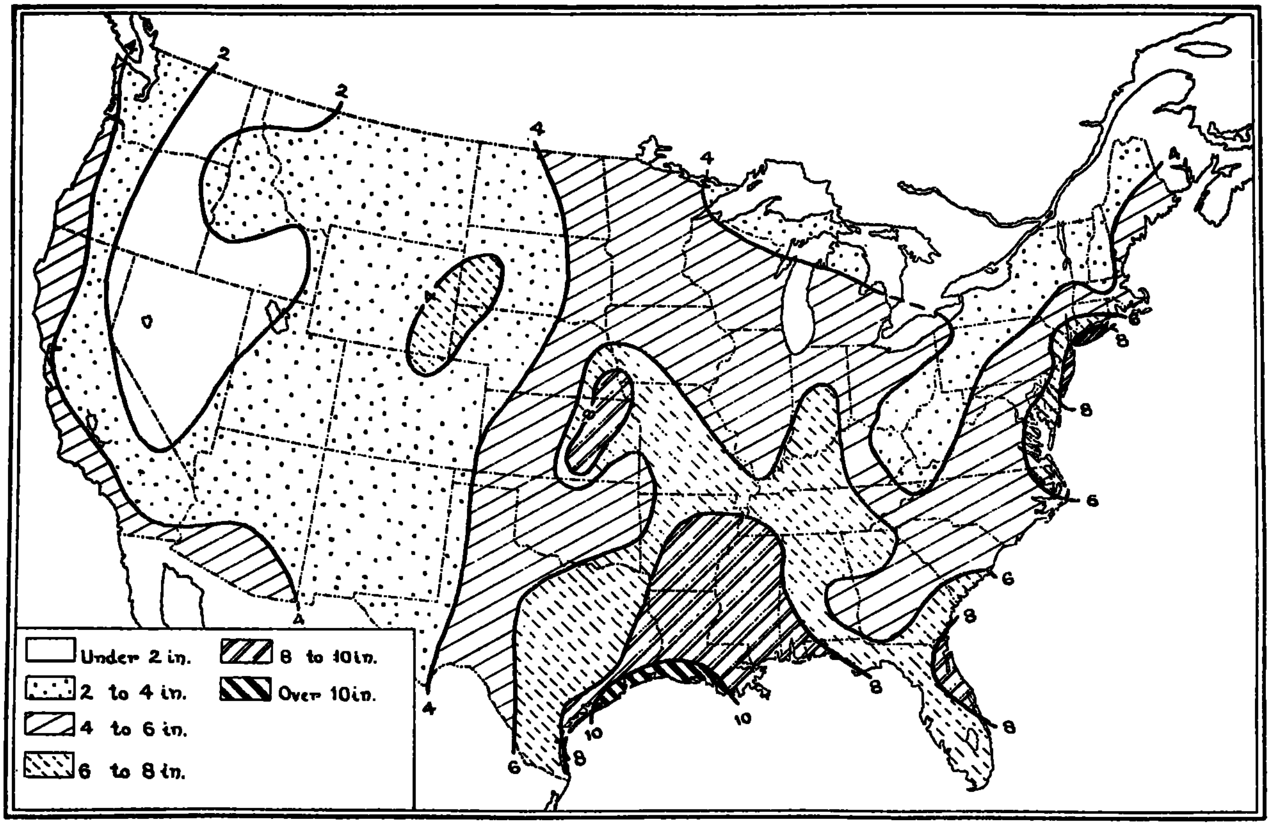

FIG. 1.—Maximum precipitation in 24 consecutive hours, in inches (1895–1914).

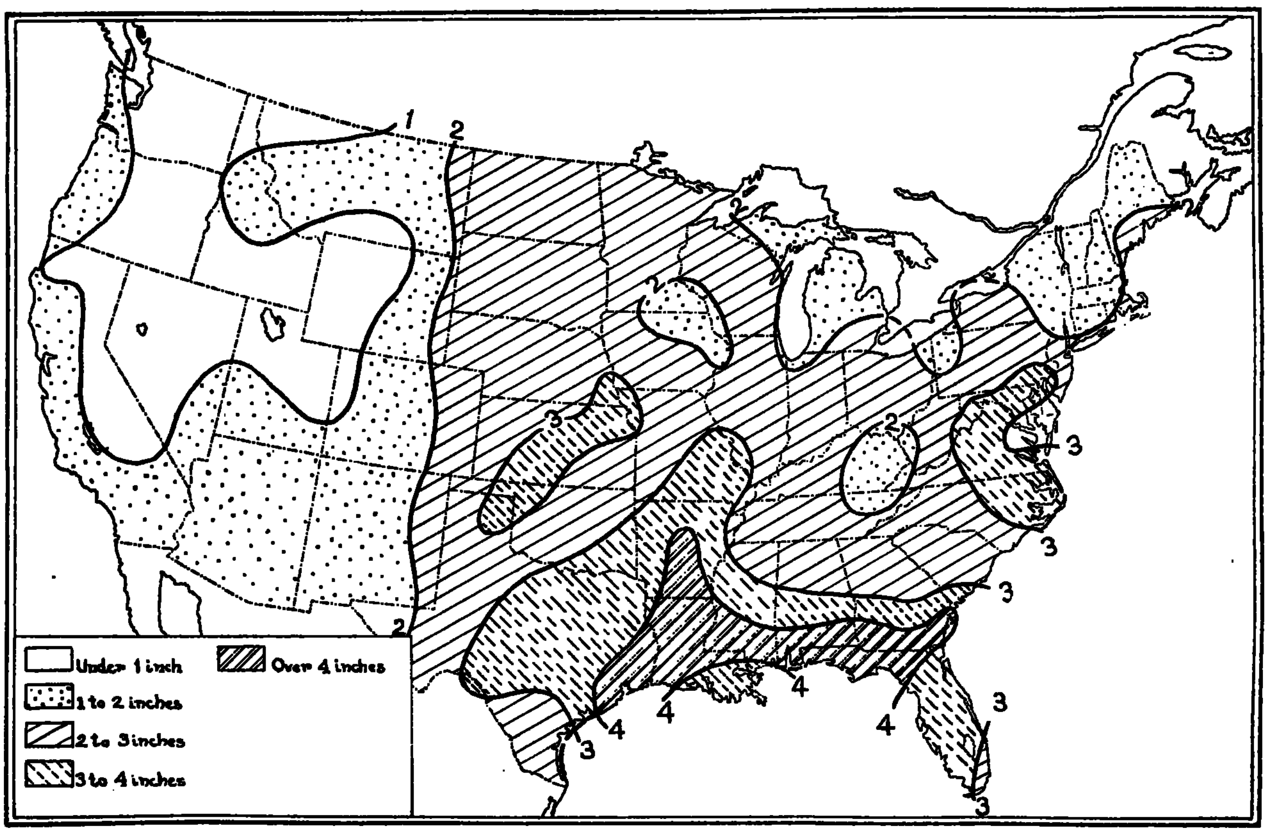

FIG. 2.—Maximum precipitation in one hour, in inches (1895–1914).

Frequency and intensity of precipitation.—Of critical importance in agricultural operations is the frequency and intensity of precipitation. One section may have a good deal less rainfall in the course of a year than another, and yet the former, because of a better distribution, and of a less torrential character of the rains, may offer more favorable conditions for agriculture. Special attention is therefore given to this subject. For each of the seasonal and monthly, and also for the warm-season precipitation charts, smaller charts are given which show the average number of rainy days (0.01 inch or more) (figs. 12, 24, 27, 34–37, 44–47, 54–57). Perhaps the most striking fact here brought out is this: In eastern sections the mean annual rainfall increases from north to south, but the frequency of occurrence (number of rainy days) often increases from south to north, especially in spring. In other words, rain falls at shorter intervals where the total annual amount is less, thus compensating to some extent for the smaller amount. However, the rule does not always work. For example, the number of rainy days is small in the drier western section, while on the northern Pacific coast, where the annual amounts are large, the number of rainy days is also large. Two full-page diagrams show, for eight selected stations, the daily amounts of precipitation during the four years 1911–1914 (figs. 68A, 68B.)

For the whole country, the average annual number of days with precipitation of 0.01–0.25 inch, 0.26–1.00 inch, more than 2 inches (figs. 71–73) brings out some interesting facts. The average annual number of days with *light* (0.01–0.25 inch) rains is less than 20 in southeastern California and reaches 120 along the North Pacific coast and in the upper Lake region. The average annual number of days with *moderate* (0.26–1 inch) precipitation ranges from less than 10 in the far Southwest and in parts of the interior plateau region to 50 days along the north Pacific coast and in the central Applachian Mountain region. In the warm season (April–September) rain occurs on the average on between 40 and 60 days over the principal agricultural districts east of the Rocky Mountains (fig. 12). During the 20-year period, the heaviest rainfalls in 24 consecutive hours varied from over 10 inches along the Gulf Coast in Texas and Louisiana to 4 inches over the Plains and the Northeastern States (fig. 70 in *Atlas*, fig. 1 here). On the north Pacific coast the 24-hour amounts have not exceeded 5 inches, although the mean annual rainfall is heaviest there. The average number of days with over 1 inch of precipitation in an hour ranges from less than one day in the West and northern Lakes area to six days along the Gulf coast (fig. 74). The maximum hourly rainfall (1895–1914) has varied between less than 1 inch over most of the country west of the Rocky Mountains to about 4 inches over the central Gulf coast States (fig. 75 in *Atlas*, fig. 2 here). Rains of the "cloud-burst" type, bringing very much larger amounts, occasionally occur in the southwestern interior. Over the Middle and South Atlantic States and the lower Missouri valley there occurs on the average about once in a season (March–September) a period of 20 or more consecutive days without 0.25 inch of rainfall in 24 hours (fig. 66). Taking the same rainfall amounts and season, but a period of 30 or more consecutive days without 0.25 inch in 24 hours, it is seen that the fewest such drought periods are found in the Middle and South Atlantic States, the Upper Ohio valley, and the northern parts of New York and New England, where they occur on an average about once in three seasons (fig. 69). The longest period of consecutive days without 0.25 inch rainfall in 24 hours during each warm season for 20 years has also been worked out for selected stations east of the Rocky Mountains (fig. 67).

Day and night rains.—The percentages of rainfall occurring between 8 p. m. and 8 a. m., seventy-fifth meridian time, during the warm season have been charted (fig. 9). The facts here indicated are of great economic importance. Over the great agricultural States east of the Rocky Mountains large sections receive over half and considerable areas receive about two-thirds of their warm season rains at night. There is, therefore, much less rapid evaporation of the fallen rains from the surface, the moisture penetrates more deeply into the soil, a crust is less likely to form on the cultivated surface, and harvesting and threshing are carried on to the greatest advantage. It is to be noted, further, that the dominant night rains occur in an important wheat area, and particularly in the harvest season. The district of maximum day rainfall is in the southeast. West of the Rocky Mountains the summer rainfall is about equally divided between day and night, except in Arizona.

Snowfall.—The maximum annual depth of snowfall shown on the new average annual snowfall map (fig. 76) anywhere in the United States is 527 inches, over the central Sierra Nevada. The next greatest depth shown is 459 inches, over the northern Cascades, in Washington. Then follow 430 inches over the Cascades of Oregon, 337 inches on the mountains of the Colorado-New Mexico border, 289 inches in north-central Colorado, and 246 and 247 inches in Idaho and in northeastern Oregon, respectively. The heaviest snowfalls in the United States are those of the mountains of the Pacific coast (400–500 inches in some places). The Rocky Mountains have less snow, as is to be expected from their more continental location. Nevertheless, 200–300 inches and more are recorded for some of their western slopes. The greatest depths of snow in the eastern United States occur from northern Michigan to New England. The Adirondack Mountains of New York State have 150 inches, and part of the Lake shore of northern Michigan has 120 inches. To the south there is a rapid decrease, the amounts in the Gulf province being negligible (under 1 inch). With the exception of southern Florida and the lower elevations of southwestern Arizona and southern California, more or less snow falls in all parts of the United States. On the immediate west coast south of latitude 42° it is practically unknown. The snowfall over the Plains ranges from about 1 inch in central Texas to about 20 inches in northern Kansas, and 20–30 inches farther north.[6]

The average number of days (not necessarily consecutive) during which the ground is covered with snow east of the Rocky Mountains decreases from four months (120 days) along the northern border to one day in the central portion of the Gulf States (fig. 78 in *Atlas*, fig. 3 here). West of the Rocky Mountains the data concern the lower altitudes only. Most of the central Plateau province has from one to two months of snow cover; the northern Pacific coast, less than 10 days; southwestern Arizona, 0 days. A new chart (fig. 79 in *Atlas*, fig. 4 here), gives the average annual number of days on which snow falls (0.01 inch or more, melted). The range is from one day over the Gulf province and the central and southern

[6] In connection with snowfall, reference may be made to the following: Charles F. Brooks, "The Snowfall of the United States," *Quart. Journ. Roy. Met. Soc.*, vol. 39, 1913, pp. 81–84; R. De C. Ward: "The Snowfall of the United States," *Sci. Month.*, vol. 9, 1919, pp. 397–415.

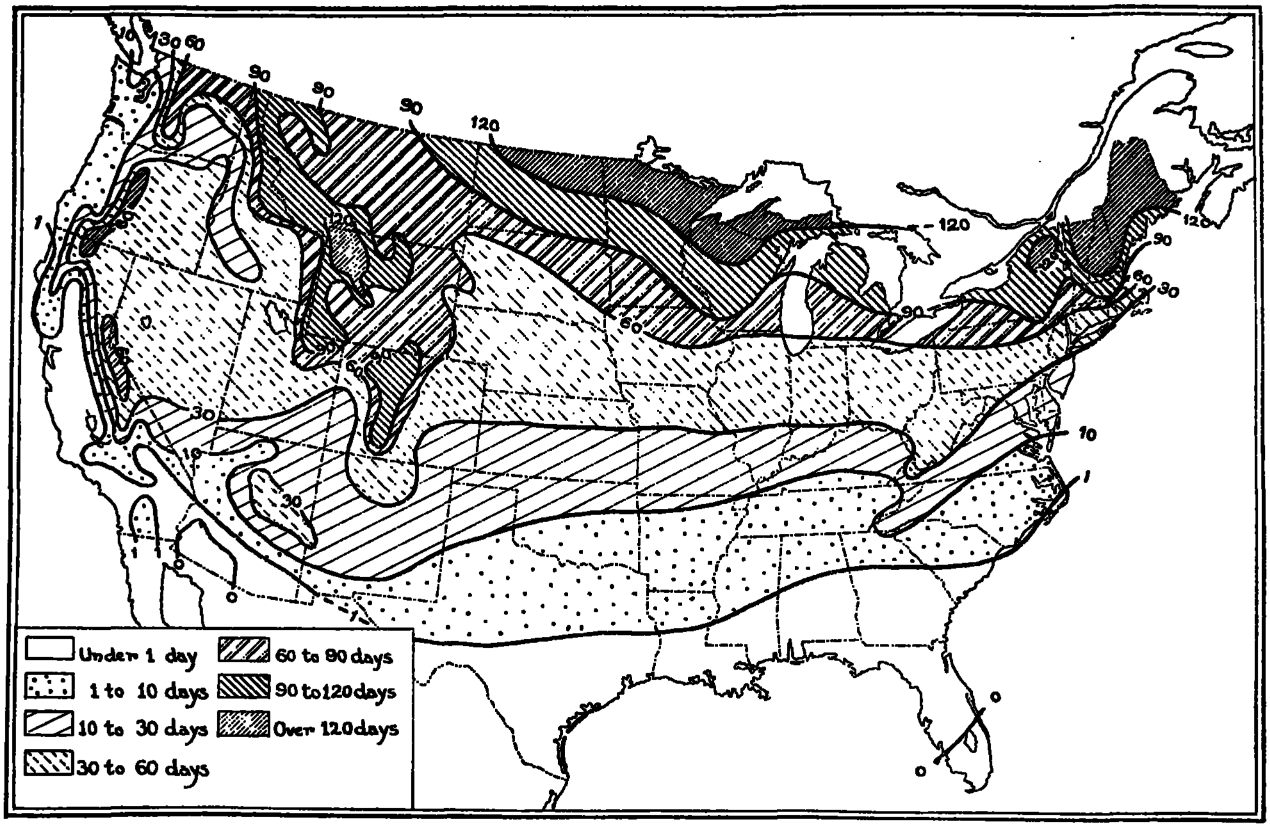

FIG. 3.—Average annual number of days with snow cover.

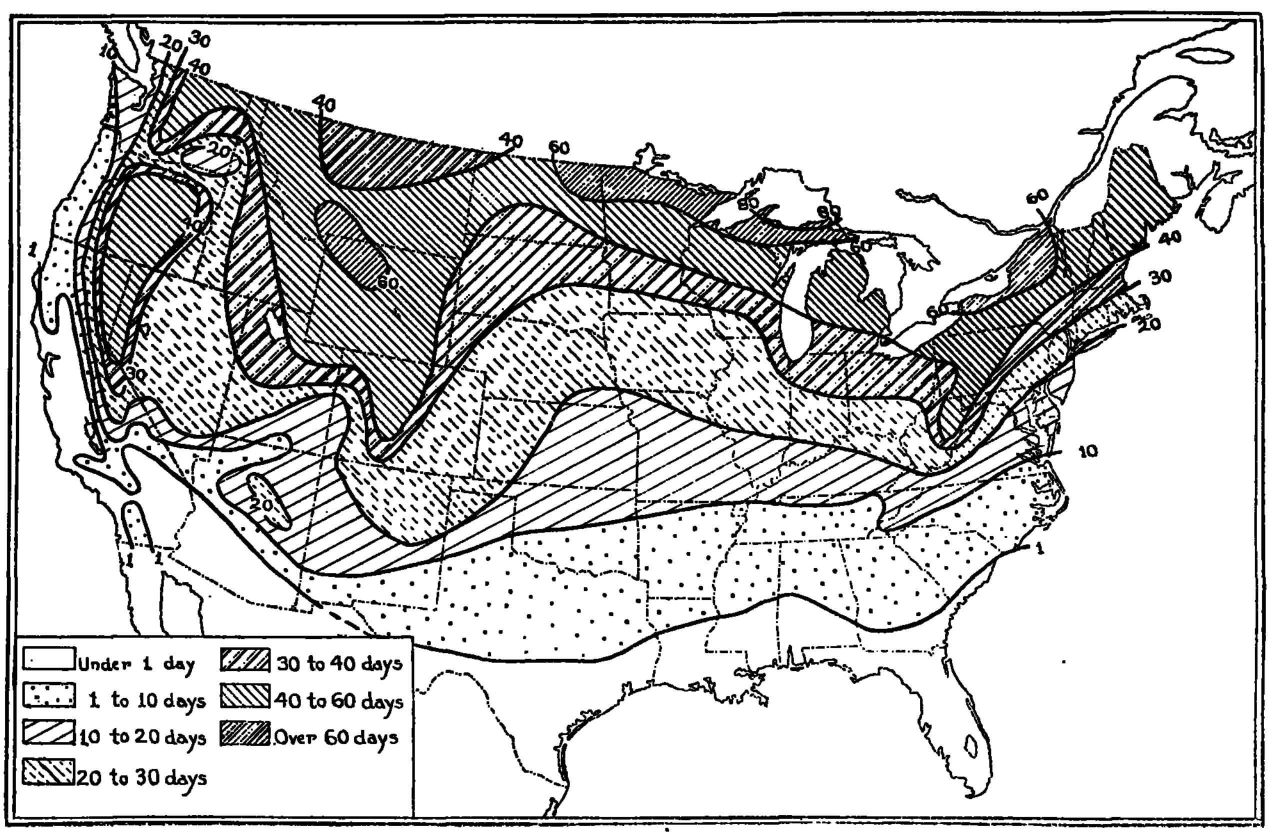

FIG. 4.—Average annual number of days with snowfall (0.01 inch or more, melted).

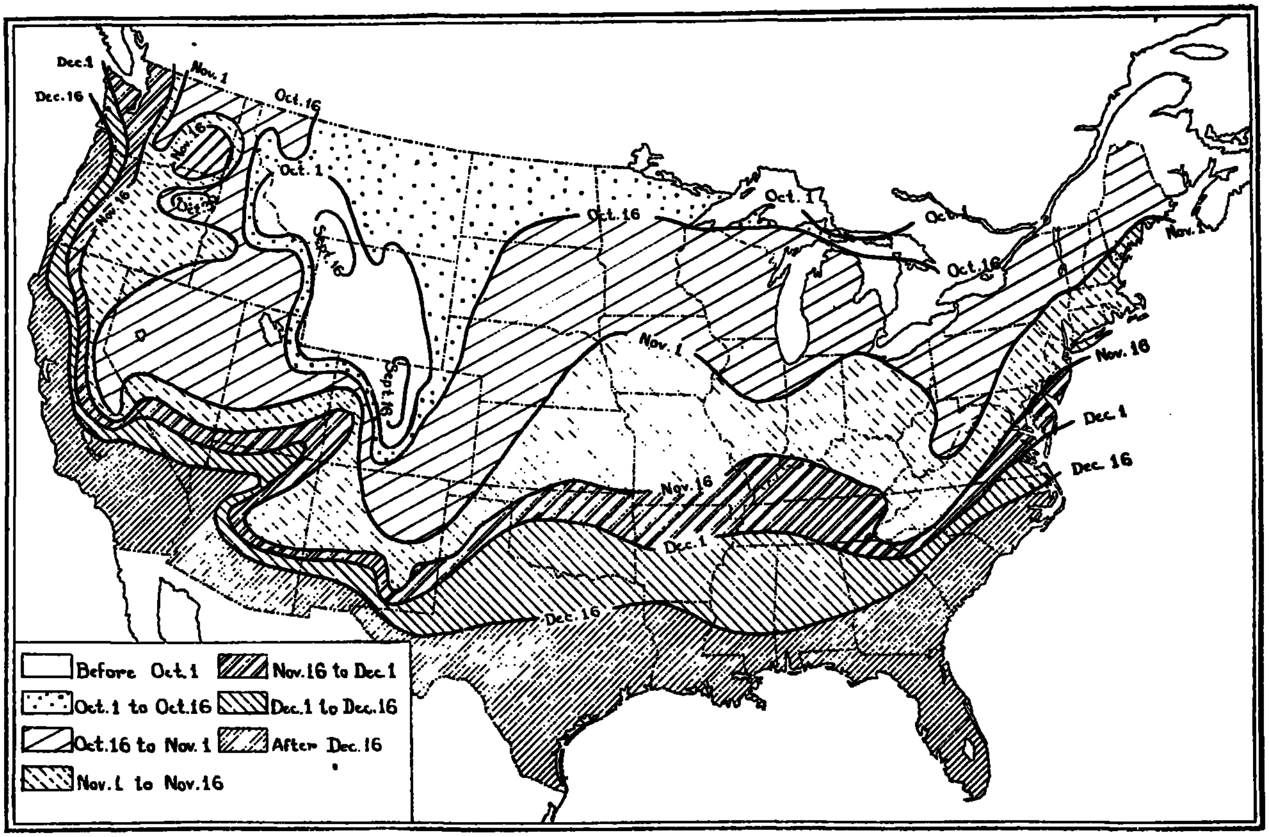

FIG. 5.—Average date of first snowfall in autumn.

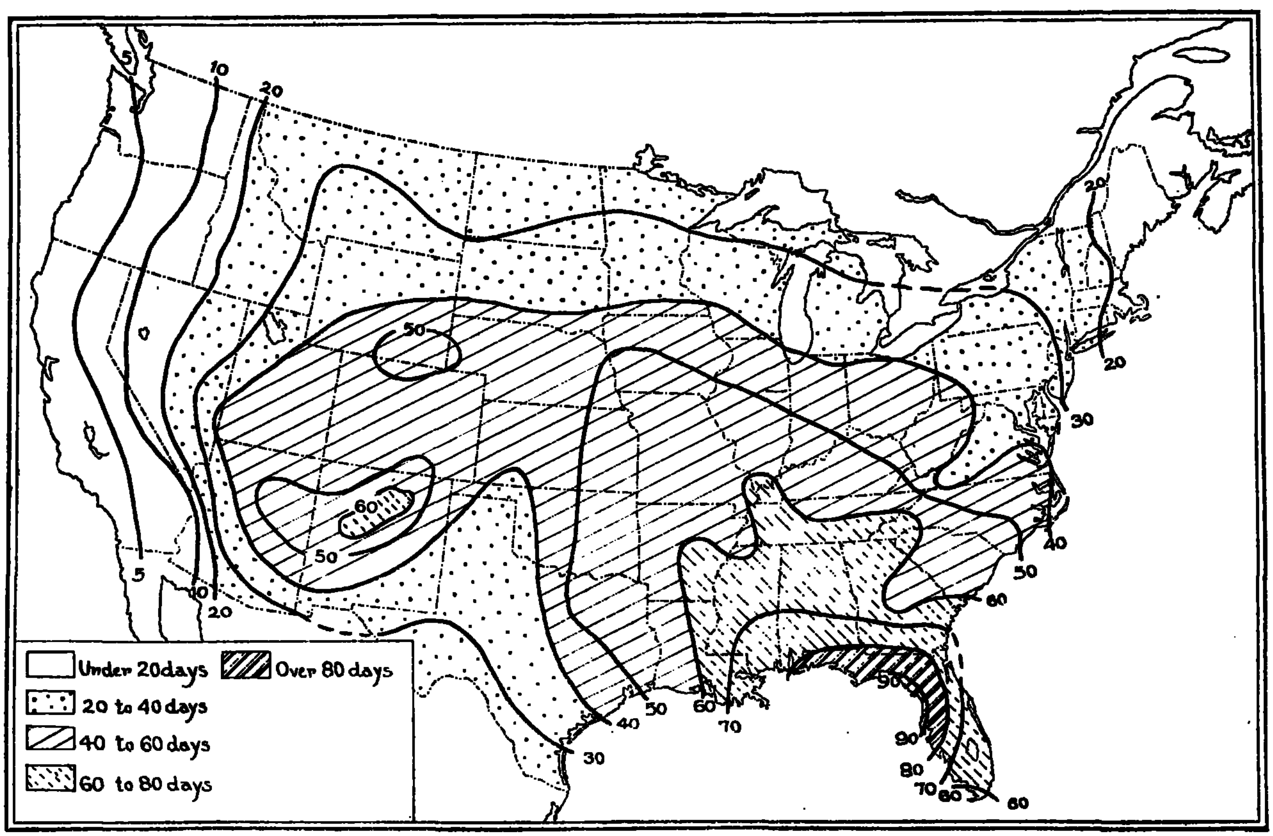

FIG. 6.—Average annual number of days with thunderstorms (1904–1913).

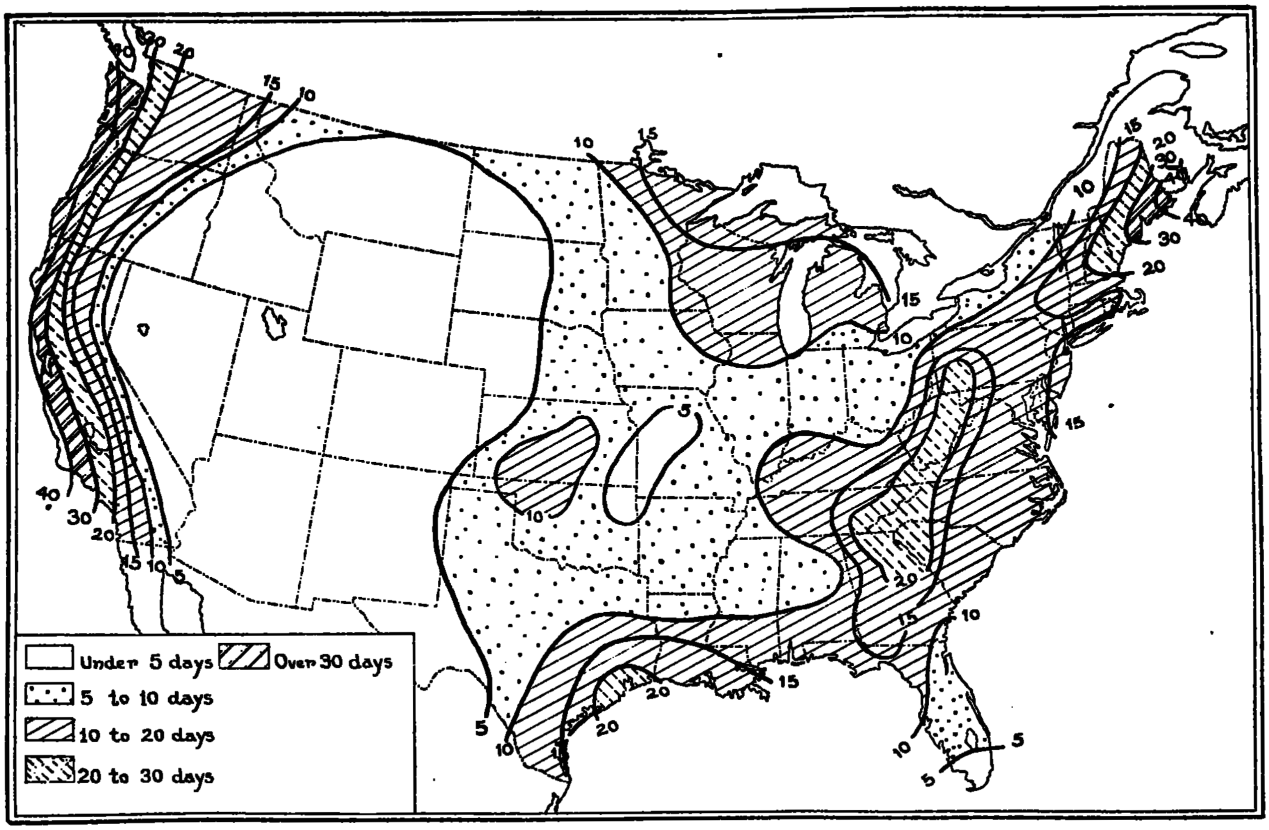

FIG. 7.—Average annual number of days with dense fog (1895–1914).

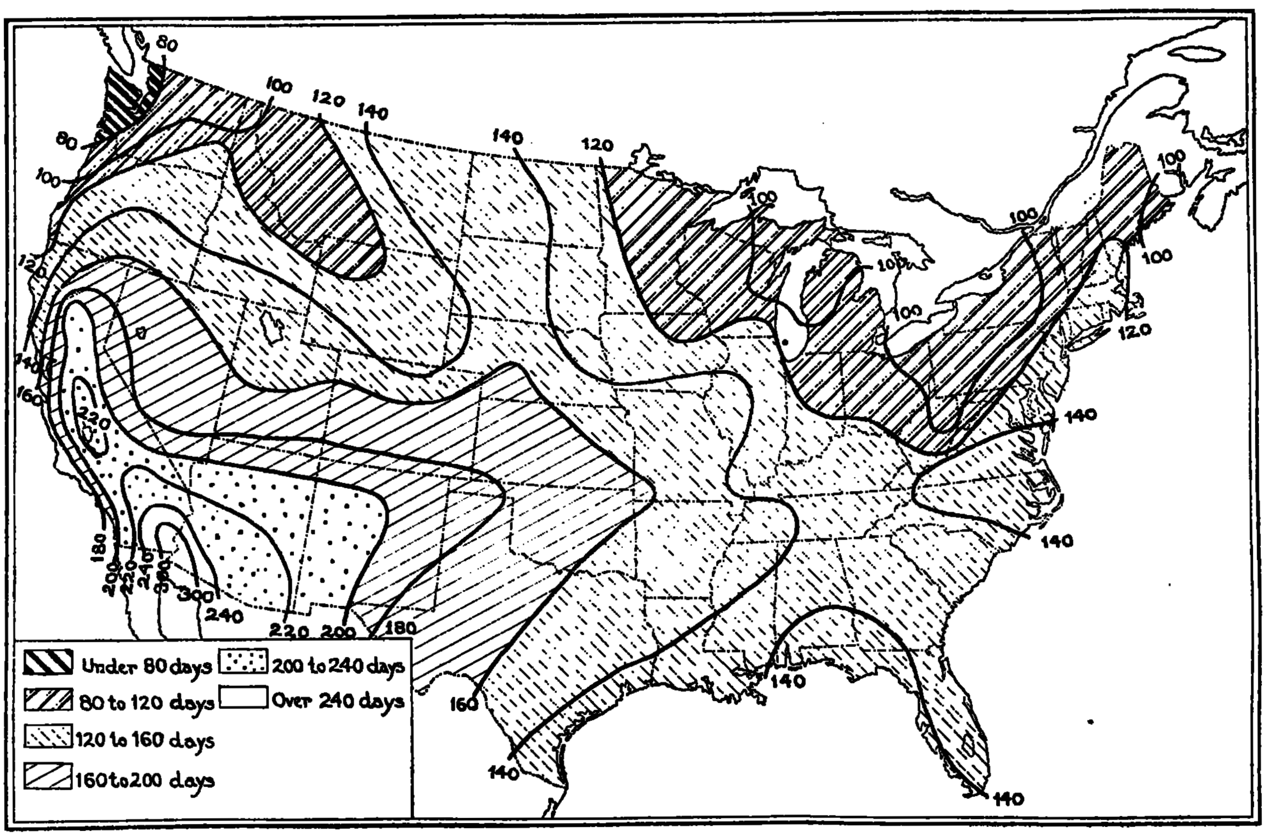

FIG. 8.—Average annual number of clear days (1895–1914).

California lowlands to 80 days in extreme northern Michigan. In the West no attempt is made to take account of the greater elevations. Considerable popular interest attaches to the average date of first autumn snowfall (fig. 77 in *Atlas*, fig. 5 here). The earliest date is before September 16 locally in the Rocky Mountain region; October 1 in extreme northern Michigan; December 16 in the central portions of the South Atlantic and Gulf States. Farther south, snow falls very irregularly, or may often not occur at all during a whole winter, as along the Gulf coast.

Thunderstorms and hail.—Another quite new chart shows the average annual number of days with hail during the crop-growing season (fig. 80). The Plains States and the Rocky Mountain area have the most frequent hailstorms. East of the Mississippi, hail occurs on the average only about once a year during the crop season. Thunderstorms have their greatest frequency (80 to 90 days annually) on the central and estern Gulf coast, a considerable section of the southeastern United States having over 60 thunderstorm days a year (fig. 81 in *Atlas*, fig. 6 here). On the Pacific coast, thunderstorms are usually recorded on not more than two to four days annually.

Fog and cloudiness.—The first fog map of its kind for the United States (fig. 82 in *Atlas*, fig. 7 here) gives the distribution of the average number of days with dense fog (dense fog obscures objects at a distance of 1,000 feet from the observer). The Pacific and the northern Atlantic coasts have the greatest fog frequency (over 40 days a year). Over the interior districts there are generally fewer than 10 days a year with dense fog. The western Gulf has over 15, as has the upper Lake region. Two charts showing the average number of clear and of cloudy days complete the folio (figs. 83 and 84 in *Atlas*, figs. 8 and 9 here). Fewer than 100 clear days a year are usually recorded in the Lake region and on the northern Pacific coast, while in the southwestern interior there are more than 300 clear days. Cloudy days average 160 a year in northernmost Michigan and 180 a year on the northernmost Pacific coast. Fewer than 20 days a year are, as a rule, cloudy in southwestern Arizona and southeastern California.

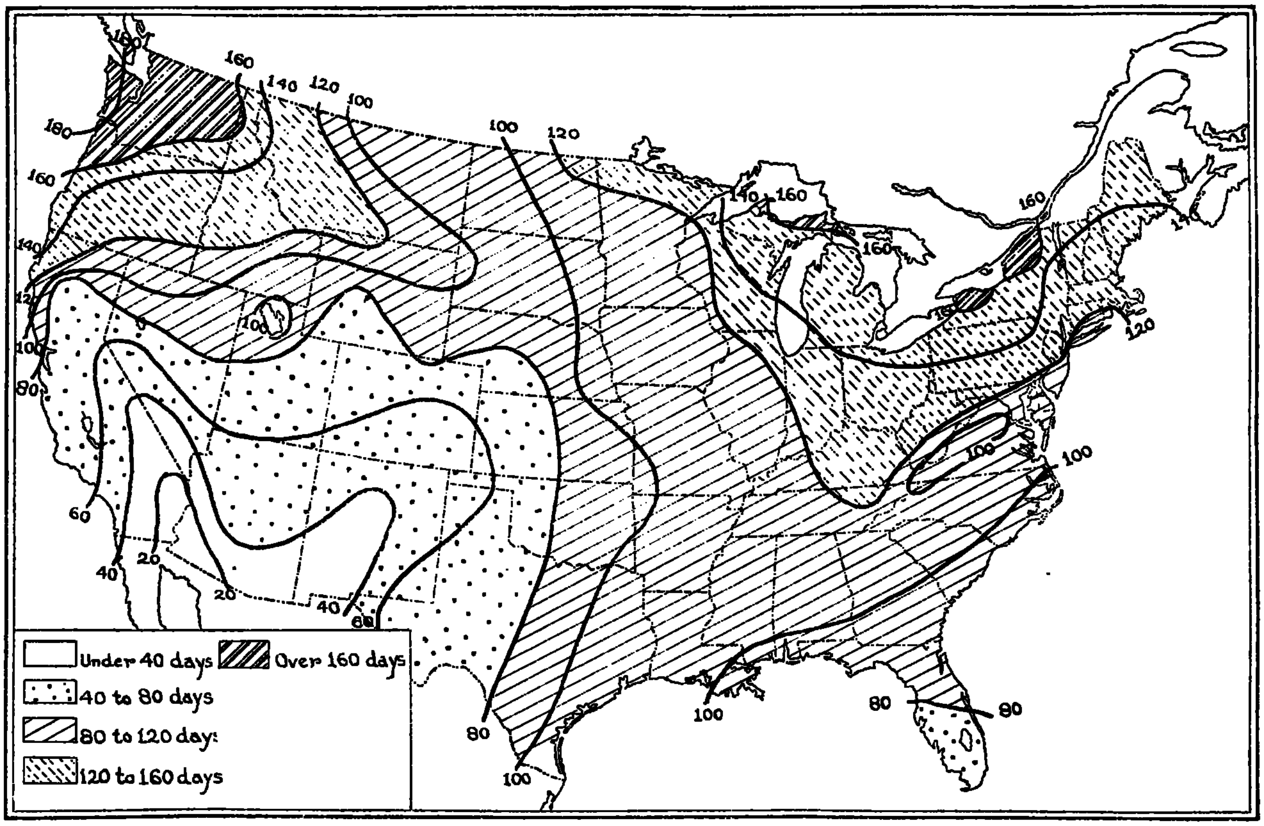

FIG. 9.—Average annual number of cloudy days (1895–1914).

To do full justice to the new precipitation folio is quite impossible in a discussion such as this, which must necessarily be little more than a catalogue of the new charts, with a few words of description in each case. The cartographic work is excellent; the colors on the maps are well chosen; the text, while brief, is quite adequate. The whole folio deserves, and will surely receive, very careful and serious study on the part of all who have any interest in United States climates, and will do much to establish American climatology on a higher plane of scientific accuracy.